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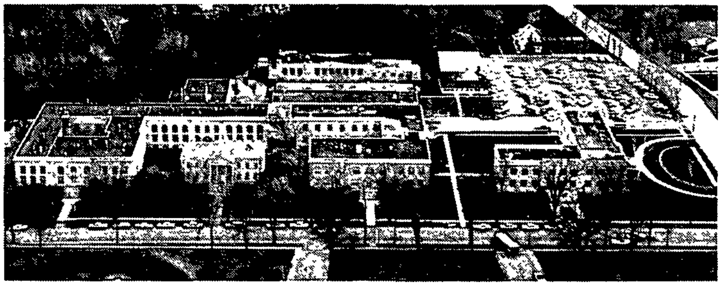

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THE IPC PAPER THICKNESS GAGE

KEITH W. HARDACKER

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INTRODUCTION

It has been recognized for many years that the measurement of paper thickness by the usual TAPPI Method T441, despite its simplicity and ease of use, is not always satisfactory. For instance, the measurement is pressure sensitive, the results for stacks of paper are not identical with those for single sheets, and the measured thickness does not agree with the thickness calculated from the mechanical properties of the sheet or from mercury displacement measurements. Determination of paper density is confused by the uncertainty of the thickness measurement. Consequently, about 1974 it was decided to investigate these discrepancies by constructing a thickness gage using the platens specified in the TAPPI method, but with extra-rigid construction, higher sensitivity, and the capability of varying the platen pressure from about 7 to 225 kPa (spanning the TAPPI specified pressures of 50 kPa).

The resulting gage, Model I, incorporates a sturdy aluminum frame, a measuring probe which is vertically guided with low-friction studs, and a linear variable differential transformer (LVDT) which senses probe position. The gage proved quite useful and led to the early stages of the development of the "rubber micrometer" (1).

Some time later, work by Baum *et al.* using ultrasonic techniques for measuring the elastic properties of paper pointed to the need for an apparatus to measure the thickness of a paper specimen as it was being compressed between the faces of two ultrasonic probes (a transmitter and a receiver). The general design of the IPC Paper Thickness Gage appeared to have the stability and sensitivity required, so a second such device was constructed.

This also provided the opportunity to incorporate several improvements. Principal among these is the use of selected-fit graphite pistons sliding in a precision-bore glass tube to provide virtually friction-free axial motion of the measurement probe while restraining its lateral motion to insignificant levels. Additional modifications included mounting the LVDT concentric with the probe axis, counterweights for the probe so that the probe pressure could be reduced to zero, and a motor drive to raise and lower the measuring probe.

This Model II gage (1980) has been used for study of the "rubber micrometer" and the effects of platen pressure and multiple sheets on measured thickness (1), and in the ultrasonic determination of the out-of-plane elastic properties of paper (2).

An increasing demand for ultrasonic measurements necessitated the construction of a third gage in 1982. A description of this Model III gage is presented below.

GENERAL DESCRIPTION

Frame

Figure 1 is a photograph of the IPC Paper Thickness Gage, Model III. It is constructed on a bolted framework of aluminum plates. The horizontal base plate is 1.5 inches thick to provide great stiffness. (If this plate is assumed to bend as a simple beam, the calculated deflection and error in measurement from this source if calibrated at zero load is less than 0.1 μm when a load of 10 kg is applied to the specimen.)

Lower Platen Support

The lower platen support is a 2-inch-diameter rod threaded into the base plate and locked in the desired position with a large nut. Thus, platens

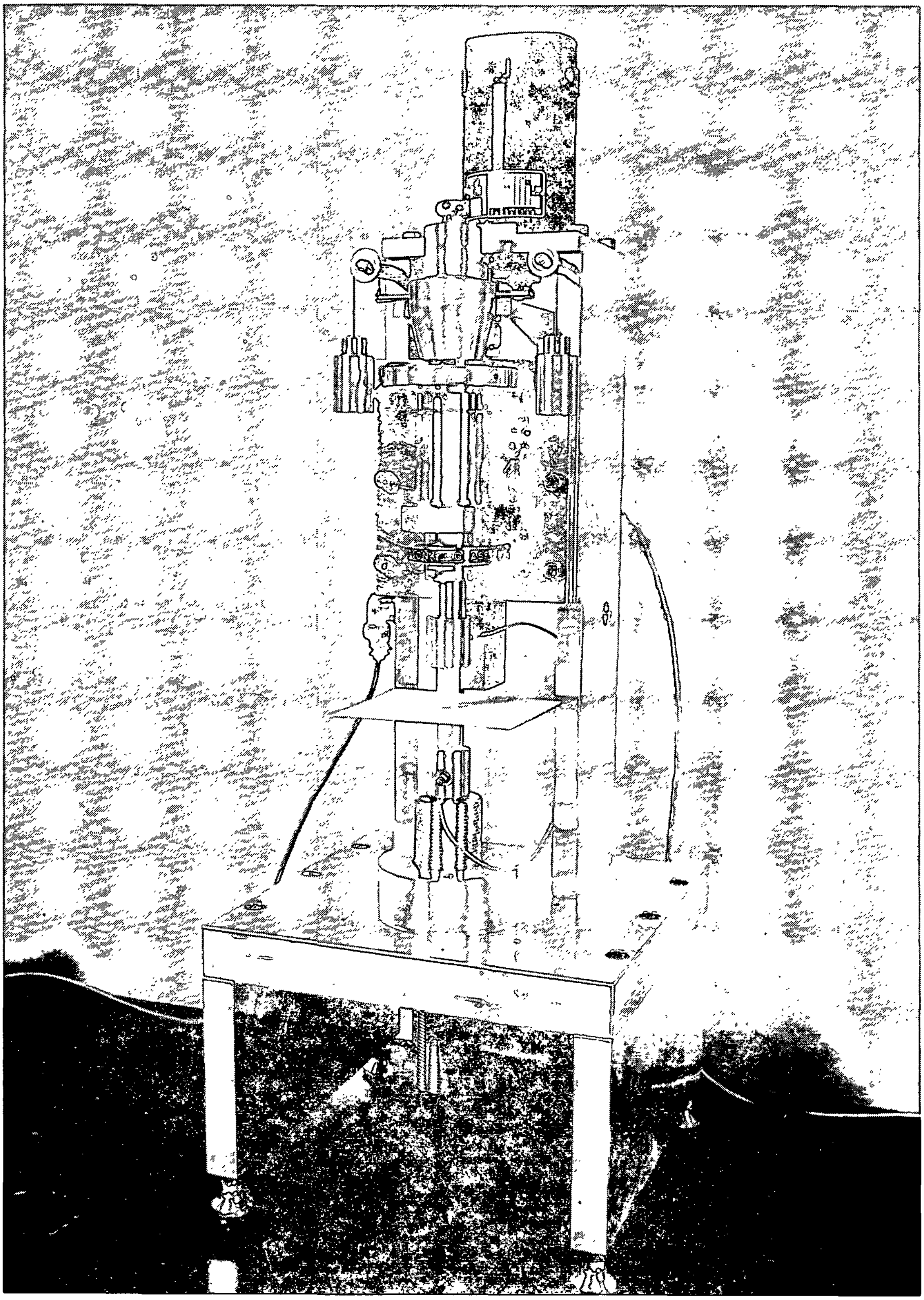

Figure 1. The IPC Paper Thickness Gage, Model III. A paper specimen is in place between two ultrasonic transducer probes.

from the very short "button" one used for conventional thickness measurement to the rather long probe structures required for the ultrasonic measurements can be accommodated. Figure 1 shows a pair of ultrasonic transducers mounted in the gage.

Probe

The probe is located directly above the lower platen support. Figure 2 is a cross section of this structure. The low-friction guiding mechanism consists of two graphite pistons moving in a precision-bore, glass tube (3). This glass tube is held by an O-ring near its lower end and by a laterally adjustable aluminum ring near its upper end to assist in trimming the parallelism of the platen faces.

The probe tube is made from an aluminum oxide thermocouple well (4) to avoid the use of metal, which would reduce the sensitivity of the LVDT. It carries the upper platen at its lower end and a platform for adding weights at its upper end. The weight of the probe assembly is counterbalanced by two hanging weights, as can be seen in Fig. 1. Loads from 0 to more than 12 kg have been applied to specimens, although extreme care is required in adding the very high loads to the lowered probe. (For TAPPI conditions, the load is a mass of 1 kg.)

LVDT and Readout

Probe position is sensed by an LVDT (5). As shown in Fig. 2, the LVDT coils fit around the outside of the glass tube, while the LVDT core is mounted on the probe axis.

A schematic of the readout unit for the LVDT is shown in Fig. 3. The signal conditioner (6) and digital display (7) provide direct reading over a

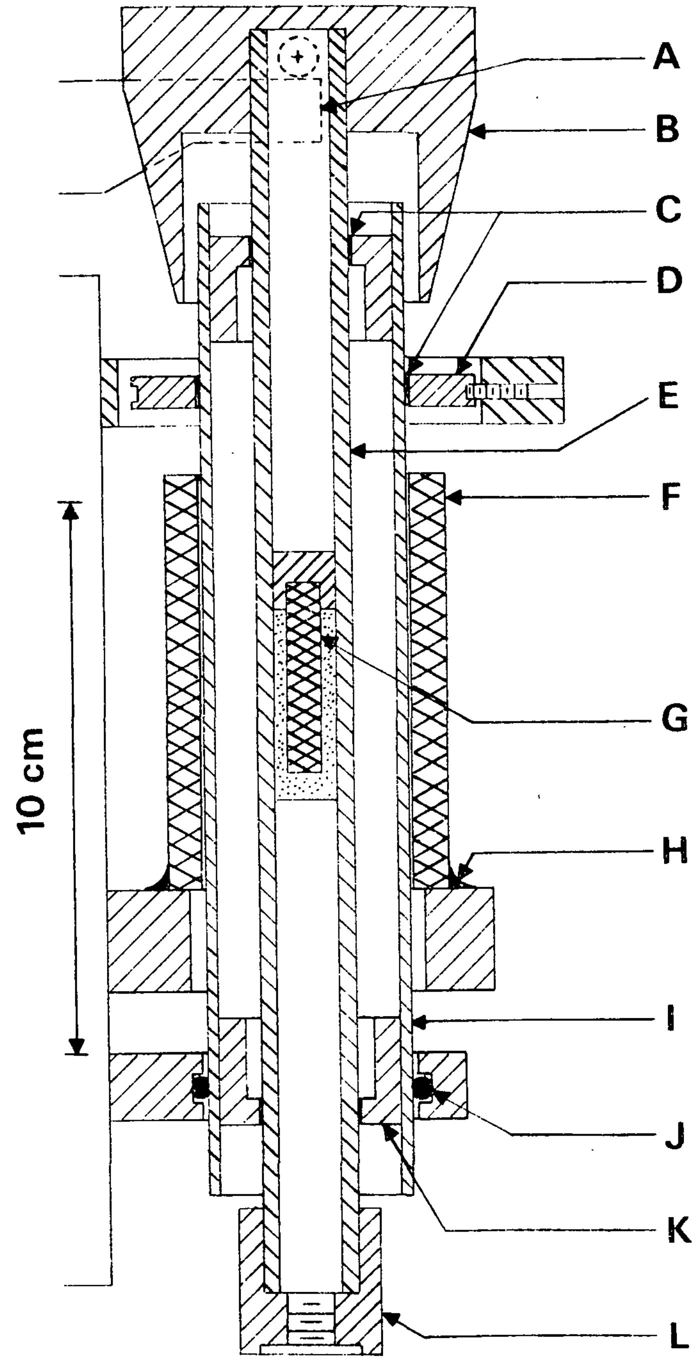

Figure 2. Cross section of the probe structure. A. One of two arms for raising the probe. B. Dust cap and weight platform. C. Epoxy cement. D. Adjustment ring. E. Aluminum oxide probe tube. F. Coils of the LVDT. G. Core of the LVDT; seated and positioned in a thermoplastic cup, then potted in a resilient dielectric. H. Silicone cement. I. Precision bore glass tube. J. Rubber O-ring. K. One of two graphite pistons. L. Metal end for attaching probe tips.

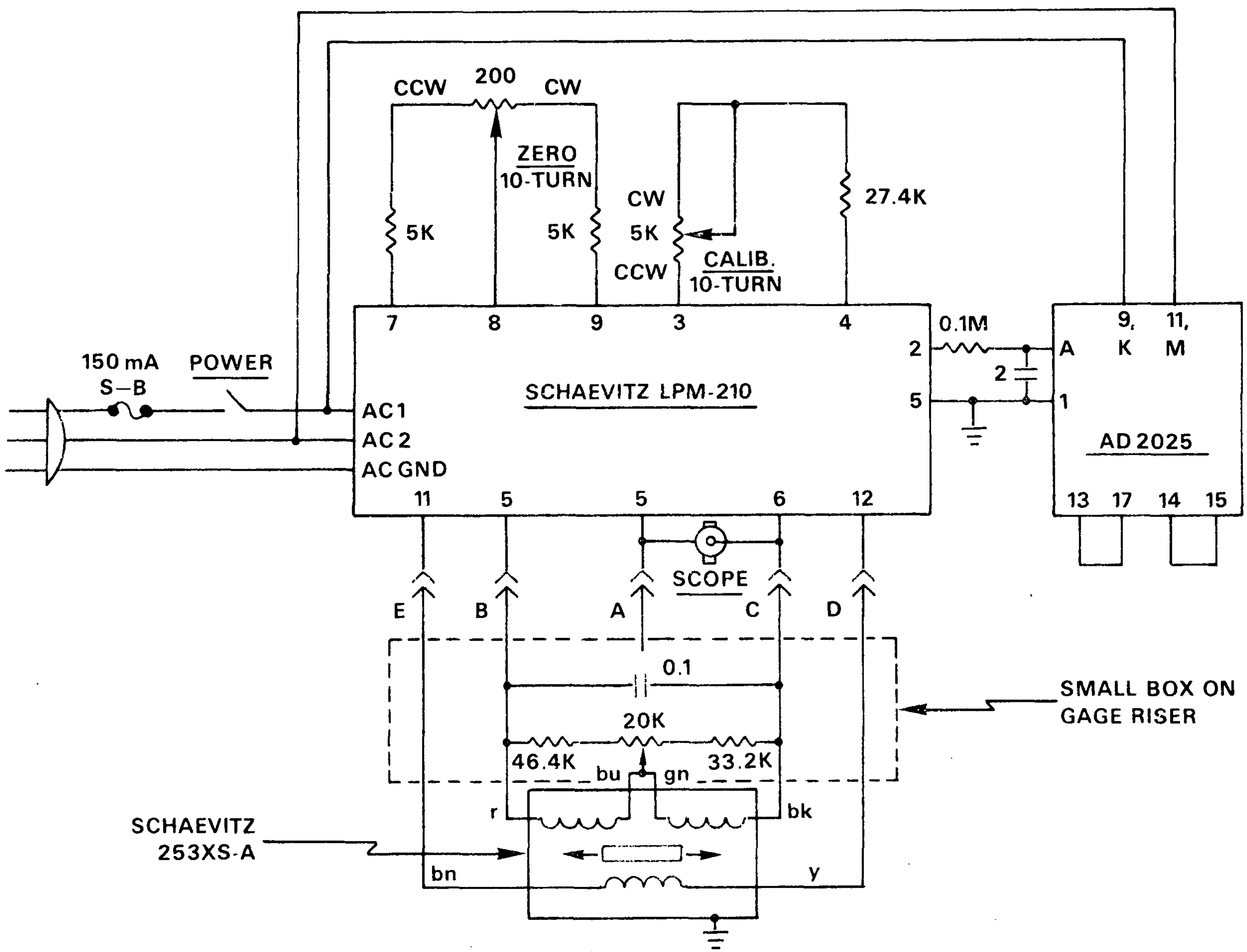

Figure 3. Schematic diagram of the thickness readout unit.

4-mm range to a resolution of 0.1 µm. At 73°F, 50% RH, repeatability is 0.1-0.2 µm; drift, about 1-1.5 µm/8 hr, noncumulative. Accuracy, of course, depends on calibration.

Probe Lifter

Raising and lowering of the probe is done with the aid of a variable-speed electric motor (8) which, through a step-down belt drive, turns the translating screw of a vertically-mounted slide assembly (9). Two arms project from the slide, one on each side of the probe weight platform. As can be seen in Fig. 1, these lift and lower the probe by pressing against pins projecting from the weight platform. When the arms are fully lowered, they are positioned a short distance below the pins so as not to interfere with the thickness measurement.

OPERATION

Setup

Mechanical setup of the system requires the following:

1. Install the desired platens or ultrasonic transducers.
2. Adjust the vertical position of the lower platen support so that a zero reading of the gage is obtained within the zero-setting range of the ZERO control of the readout unit.
3. Adjust the probe and the lower platen support to obtain parallelism of the platen faces.

Hard Platen Calibration

When used as a gage with hard platens, the calibration procedure is as follows:

1. Set the weight to be used on top of the probe. Then bring the clean platens together with no specimen in place.
2. Adjust the ZERO control so that a reading of zero is obtained.
3. Insert a clean shim of known thickness. Adjust the CALIBRATION control to obtain a meter reading equal to the shim thickness. The instrument should now be direct reading.

Rubber Platen Calibration

As explained in Ref. (1), rubber platen measurements are made with a sheet of 5-10 Durometer, solid Neoprene rubber on each side of the specimen. The soft rubber (10) tends to conform to the surface of the paper specimen, giving measured thicknesses in good agreement with those obtained by effective thickness and mercury displacement methods.

The calibration procedure used with hard platens is not applicable to use with rubber platens because the deformation pattern of the loaded rubber platens with no specimen in place is somewhat different from the pattern when a specimen is in place and providing some lateral restraint. Consequently, the following calibration procedure is suggested:

1. Set the weight to be used on top of the probe. With the rubber platens in place, insert a shim (11) of known thickness (X_1) and record the meter reading (Y_1).
2. Replace the first shim with a second shim of known, greater thickness (X_2) and record the meter reading (Y_2). Leave the second shim in place.

3. Calculate the meter reading for a shim of zero thickness:

$$Y_3 = (X_1Y_2 - X_2Y_1)/(X_1 - X_2).$$

(This is the Y-axis intercept of the straight line through the points X_1,Y_1 and X_2,Y_2).

4. Calculate

$$Y_4 = Y_2 - Y_3.$$

Then turn the ZERO control so that the meter reads Y_4. (This line now passes through the origin; i.e., zero thickness reads zero.)

5. Turn the CALIBRATION control so that the meter reads X_2. (The line slope is changed.) Remove the shim. The instrument should now be direct reading, but it may be necessary to iterate the preceding steps to obtain the desired accuracy.

REFERENCES AND COMMENTS

1. Wink, W. A. and Baum, G. A. A rubber platen caliper gage - a new concept in measuring paper thickness. Tappi J. 66(9):131-3(Sept., 1983).
2. Fleischman, E. H., Baum, G. A., and Habeger, C. C. A study of the elastic and dielectric anisotropy of paper. Tappi 65(10):115-18(Oct., 1982).
3. Airpot piston/cylinder assembly, Part No 64613-1; 325-7.125 piston/cylinder with two matching pistons. Airpot Corporation, 27 Lois Street, Norwalk, CT 06851.
4. High purity alumina protection tube, 7/16 inch x 11/16 inch x 12 inches, plain; Part No. 265801. Leeds and Northrup Company, North Wales, PA 19454.
5. Linear variable differential transformer, Type 253XS-A. Schaevitz Engineering, P.O. Box 505, Camden, NJ 08101.
6. Signal conditioner, Type LPM-210. Schaevitz Engineering.

7. Digital panel meter, Model AD-2025. Analog Devices, P. O. Box 280, Norwood, MA 02062.

8. Adjustable speed control, Model SLF58UD4, uncased; reversing contactor module, No. EC-115; motor, Bodine 020. Minarik Electric Company, 332 E. Fourth Street, Los Angeles, CA 90013.

9. Unislide assembly, Catalog No. A4006 C, with 5-inch slider. Velmex, Inc., P.O. Box 38, Bloomfield, NY 14443.

10. Super-soft Neoprene, 5 to 10 Durometer, approximately 1/32 inch x 12 inches x 12 inches. Crane Packing Company, 6400 Oakton Street, Morton Grove, IL 60053, ATTN: Charles Mugford.

    There is a $100 minimum order charge for this material. The Institute has a small supply on hand and can provide samples. Call Roger Van Eperen (414-734-9251).

11. The calibration shims used with the rubber platens must be large enough to completely fill the area being measured. Common 1/2-inch feeler gage stock is usually too narrow. The Institute has purchased the following:

    Steel gage blocks, 1 inch square, without holes, grade 2A+, with certificate traceable to the National Bureau of Standards, in the following thicknesses: 0.010, 0.020, 0.030, 0.040, and 0.070 inch. DoAll Wisconsin Company, 2725 W. Oklahoma Avenue, Milwaukee, WI 53215, ATTN: Jim Fenton.

    For working standards, household aluminum foil serves nicely after it has been solvent degreased. In fact, it has been found that such aluminum squares can serve as adequate "primary" standards in place of the steel gage blocks if their thicknesses are calculated from the density of aluminum and the very carefully measured areas and weights of the squares.